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Planting Date, Hybrid Maturity, and Weather Effects on Maize Yield and Crop Stage

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Abstract

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Comments

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ABSTRACT

Unfavorable weather conditions frequently cause farmers to plant maize (*Zea mays* L.) outside the optimum planting timeframe. We analyzed maize yield and phenology from a multi-location, year, hybrid relative maturity, and planting date experiment performed in Iowa, USA. Our objectives were to determine the optimum combination of planting date and relative maturity to maximize maize grain yield per environment and to elucidate the risk associated with the use of "full-season hybrids" when planting occurs beyond the optimum planting date. Analysis of variance (ANOVA) attributed 70% of the variability in grain yield to planting date and only 10% to relative maturity indicating that short and full-season hybrid relative maturities produced similar grain yields regardless of when they were planted as long as the crops reached maturity before harvesting. Our analysis indicated time to silking is a good indication of expected yield potential with a critical time (beyond which yield is reduced) to be 23 July for Iowa. Furthermore, we found that a minimum growing degree accumulation of 648°C-day during the grain-filling period maximized maize yield. Overall, this study brings new results to assist decision making regarding planting date by hybrid relative maturity across Iowa.

Core Ideas

- Planting in mid-May can significantly diminish Iowa maize grain yields.
- Grain yield variability is explained mostly by planting date with minor effect from relative maturity.
- Silking date is a good indicator of grain yield; silking beyond 25 July was detrimental.

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Planting date and hybrid maturity are two major strategies used worldwide for crop adaptation and mitigation to manage for unfavorable growing conditions. Planting date (PD) and hybrid relative maturity (RM) decisions set the yield potential of maize in each environment. Together with the prevailing weather, these two factors control the length of the growing season in which the crop accumulates radiation that is positively correlated with grain yield (Lindquist et al., 2005). For field crops it is accepted that early planting with a full-season RM has greater yield potential than a late planting with a short-season RM (Richards, 1996), because the larger length of the growing season allows for greater use of resources such as radiation, water, and nutrients by the crop (Andrade et al., 2000; Tsimba et al., 2013a; Parker et al., 2016). However, yield is particularly sensitive to growth and partitioning during critical periods (Andrade et al., 2000; Vega et al., 2001), an early PD and full-season hybrid does not guarantee a high grain yield because other factors such as drought, heat, and nutrient stresses can reduce grain yield during the season (Edmeades et al., 2000).

According to the literature, the optimum planting window for maize in the US Corn Belt was determined to be the last week of April (Nafziger, 1994). Within each state, there are different optimum planting window recommendations, depending on location (Sindelar et al., 2010; Abendroth et al., 2017). When maize is planted prior to or later than this optimum window, a yield decline can be observed (Zhou et al., 2016). The optimum timeframe for maize establishment usually refers to the mean weather conditions and does not apply every year. The reality is that year-to-year weather variability and poor soil conditions in the spring forces farmers to frequently plant outside the optimum window. Very early planting increases the probability of poor planting conditions due to cold, wet soils, resulting in a negative impact on plant emergence (Parker et al., 2016). For that reason, replanting maize is a practice that increases the operation cost (Benson, 1990). On the other hand, very late planting is associated with reduction in growing season length and accumulation of radiation (Nielsen et al., 2002).

In the US Corn Belt, farmers typically select the hybrids to use several months before the planting season. They make decisions based on university extension or seed company recommendations for average weather years that are usually limited

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Abbreviations: DOY, day of year; GDD, growing degree days; PD, planting date; RM, relative maturity.

Table 1. Location and soil summary for each experimental site.

Year	Site	Lat °N	Long °W	Soil series	Soil classification
2014/2016	Northwest	42.927926	95.538799	Primghar	Fine-Silty, mixed mesic, Aquic Hapludolls
	North Central	42.914641	93.789808	Canisteo	Fine-loamy, mixed, superactive, calcareous, mesic Typic Endoaquolls
	Northeast	42.942328	92.567735	Kenyon	Fine-loamy, mixed, superactive, mesic Typic Hapludolls
	Central	42.012814	93.743343	Nicollet	Fine-loamy, mixed, superactive, mesic Aquic Hapludolls
				Clarion	Fine-loamy, mixed, superactive, mesic Typic Hapludolls
	Southwest	41.327887	95.180568	Marshall	Fine-silty, mixed, superactive, mesic Typic Hapludolls
	South Central	40.971814	93.420158	Haig	Fine, smectitic, mesic Vertic Argiaquolls
	Southeast	41.203000	91.492431	Mahaska	Fine, smectitic, mesic Aquertic Argiudolls
2015	Northwest	42.928315	95.538114	Galva	Fine-silty, mixed, superactive, mesic Typic Hapludolls
	North Central	42.914867	93.790702	Canisteo	Fine-loamy, mixed, superactive, calcareous, mesic Typic Endoaquolls
	Northeast	42.940226	92.568560	Kenyon	Fine-loamy, mixed, superactive, mesic Typic Hapludolls
				Readlyn	Fine-loamy, mixed, superactive, mesic Aquic Hapludolls
	Central	42.010602	93.742283	Nicollet	Fine-loamy, mixed, superactive, mesic Aquic Hapludolls
				Clarion	Fine-loamy, mixed, superactive, mesic Typic Hapludolls
	Southwest	41.309837	95.183666	Marshall	Fine-silty, mixed, superactive, mesic Typic Hapludolls
	South Central	40.974864	93.420158	Grundy	Fine, smectitic, mesic Aquertic Argiudolls
	Southeast	41.191977	91.480351	Taintor	Fine, smectitic, mesic Vertic Argiaquolls

in number of site-years. For Iowa, a state that produces 68.6 million Mg of maize on 5.5 million ha in 2016 (USDA-NASS, 2017), PD by RM recommendations have not been updated since 2001 (Farnham et al., 2001). Furthermore, due to the short commercial lifecycle of hybrids and increased climate variability (wetter than normal springs in the US Corn Belt; Dai et al., 2015), there is a need to regularly update planting recommendations for improved farmers' decision making. A study by Sacks and Kucharik (2011) showed that the PD in the US Corn Belt is advancing 0.4 d per year over a 24-yr period. Recent findings of climatological trends showed that increased intensification of cropland in the US Corn Belt has lowered temperatures and increased precipitation amounts (Alter et al., 2017). As both temperature and precipitation impact maize development, the optimum planting date and relative maturity recommendations should be updated regularly.

Currently there is a knowledge gap regarding what hybrids to use when PD is delayed past the optimum window because of weather and soil constraints. According to a study in southern Wisconsin, full-season hybrids yield better when planted at optimum dates or earlier, and it was not until 15 May (day of year [DOY] 135) that a farmer should switch to a short-season hybrid (Lauer et al., 1999). The critical planting window at which yield reduction occurs in modern hybrids has not been estimated for Iowa. A dilemma that farmers face when planting is a delayed decision of when to switch from a full-season hybrid (with full yield potential) to a short-season hybrid (with diminished yield potential) that will mature before a killing fall frost (Nafziger, 1994; Lauer et al., 1999; Nielsen et al., 2002; Parker et al., 2016).

Our objectives were to: (i) identify optimum PD for modern hybrids to maximize yields per environment; (ii) to estimate the risk associated with full-season hybrids when planting occurs beyond the optimum date; and (iii) determine critical developmental (silking and grain-fill duration) indicators and thresholds for assessment of expected grain yield and decision making. To meet our objectives, we analyzed a comprehensive multi-location dataset from Iowa ($n = 1056$), that has maize PD and RM treatments across 3 yr.

MATERIALS AND METHODS

Experiment Sites

Field experiments were established at seven experimental sites at Iowa State University research farms in 2014, 2015, and 2016. The extent of sites and years was to fully represent the variability in climate and soils in Iowa, USA (Table 1). Of the seven sites, three were located across northern Iowa, one in central Iowa, and three across southern Iowa. Sites in northern Iowa were denoted as Northwest, North Central, and Northeast. Sites in southern Iowa were denoted as Southwest, South Central, and Southeast. Iowa has a humid continental climate with annual mean temperature of 9°C and precipitation of 900 mm and 164 frost-free days. Weather data were collected for each site using weather stations provided by Iowa's Environmental Mesonet (IEM, 2016). Long-term means were derived from 1980 to 2016.

Experimental Design and Management

Each site-year followed a split-plot design with four replications. The main plot factor was PD and RM the sub-plot factor. Individual plot size was 4.6 m wide by 13.7 m long. Row spacing was 76 cm. Maize was planted following soybean [*Glycine max* (L.) Merr.] at 86,450 seeds ha^{-1}. Fields at all sites followed typical herbicide and soil fertility programs for P, K, and pH for the area (Mallarino et al., 2013). A target N application of 168 kg ha^{-1} was applied as a single spring pre-plant application at all sites. Pesticides were used as needed to ensure pests were non-yield limiting.

Planting Date and Relative Maturity

The target PD across all site-years were 15 April (DOY 105), 10 May (DOY 130), 5 June (DOY 156), and 30 June (DOY 181). However, weather inconsistencies among sites-years created variation from the target PD as shown in Table 2. Due to variation in actual PD among site-years, the PD were grouped within five categories, April (15–30), early May (1–10), mid-May (11–20), early June (1–15), and late June (16 and after). Some of the PD in the late June category stretched into early July. An early July category was deemed unnecessary because of how few sample points fell into this category and the similarity of grain yields with those in the late June category.

Table 2. Actual planting date (PD) for each experimental site-year.

Year	Northwest	North Central	Northeast	Central	Southwest	South Central	Southeast
2014	22 Apr.	6 May	19 Apr.	21 Apr.	18 Apr.	5 May	20 Apr.
	9 May	18 May	8 May	9 May	10 May	9 May	8 May
	6 June	3 June	1 June	3 June	3 June	12 June	2 June
	3 July	9 July	28 June	8 July	3 July	26 June	27 June
2015	15 Apr.	17 Apr.	15 Apr.	15 Apr.	16 Apr.	15 Apr.	16 Apr.
	18 May	13 May	9 May	13 May	13 May	7 May	7 May
	9 June	5 June	2 June	4 June	6 June	8 June	3 June
	30 June	30 June	30 June	30 June	1 July	30 June	1 July
2016	15 Apr.	17 Apr.	15 Apr.	15 Apr.	15 Apr.	18 Apr.	14 Apr.
	9 May	18 May	9 May	16 May	15 May	10 May	9 May
	6 June	6 June	3 June	9 June	6 June	6 June	2 June
	1 July	1 July	29 June	1 July	29 June	29 June	29 June

In total, six different hybrid RM were selected from DuPont Pioneer (P9526AMXT, P0407AMXT, P0636AM, P0987AMX, P1151AM, and P1365AMX) with RM ratings of 95, 104, 106, 109, 111, and 113 d, respectively. Hybrid RM was chosen based on the hybrid's geographically adapted location. Due to this, different hybrid RM were planted in northern and southern Iowa sites following a short, medium, and full RM pattern with the northern sites having RM 95, 104, and 109 d. The southern sites contained RM 106, 111, and 113 d. The central site contained a combination of the middle and full-season hybrids from the northern and southern sites, resulting in a RM set of 104, 109, 111, and 113 d.

Measurements and Calculations

The center 4 rows of each 6-row plot were mechanically harvested using a Harvest Master weigh bucket system. The weigh bucket system collects the grain weight and moisture on an individual plot basis. This allows for higher accuracy as opposed to a yield monitoring system that determines grain weight from grain flow across an impact plate. Yield data presented in this paper were adjusted to a 150 g kg^{-1} grain moisture content.

The following crop phenological stages were recorded in the field throughout the growing season: emergence date, silking date, and physiological maturity (Supplemental Table 1). Growing degree days (GDD) were calculated using the formula (Eq. [1]):

$$\mathrm{GDD} = \frac{T\mathrm{max} + T\mathrm{min}}{2} - \mathrm{base} \quad [1]$$

where Tmax and Tmin is the daily maximum and minimum air temperature, respectively in °C, and base is 10°C. If Tmax exceeds 30°C, 30°C was used for Tmax, and if Tmin is less than 10°C, 10°C was used for Tmin (Kumudini et al., 2014). The total GDD accumulation was calculated from planting to physiological maturity. A killing frost was determined when the air temperature was at or below –2.22°C.

Data Analysis and Statistics

Relative yield was calculated by dividing the actual yield by the maximum yield observed within a site by RM combination across years and PD. An analysis of variance (ANOVA) was used to determine treatment effects on a linear statistical model. The ANOVA table was derived using R software (R Core Team, 2017). The model analyzed the interaction among study factors (site, year, PD, RM) on grain yields (Table 3). Replication across years and treatments (PD and RM) within a site were considered random effects to derive the standard deviation of the mean for each treatment, whereas site, PD, and RM were fixed effects in the statistical model. The ANOVA was run for every site separately as RM was nested within individual sites and all sites consisting of different climate patterns and soil types. Of the seven sites, none were found to have a significant interaction between PD and RM on grain yield. However, PD was significant at every site and RM was significant at only the Central site for grain yield (Table 3). A similar linear model was sufficient to compare interactions for the timing of phenological stages, interactions among sites, and the accumulated GDD and their effect on grain yield.

A quadratic model better explained how grain yield interacted across varying PD. To fit the grain yield response to PD, we used the nlme package in R and the following nonlinear model (Eq. [2]).

$$y = ax^2 + bx + c \quad [2]$$

where y is yield, x is planting DOY, and a, b, and c are coefficients specific to each site-year × RM combination. The interaction on grain yield was considered to be significant at $P < 0.05$ among sites that contain the same RM; therefore, the model was applied separately to each experimental site-year by RM combination ($n = 66$ cases). From these quadratic fits we estimated the optimum PD for each combination and integrated results by site and presented as frequency plots.

RESULTS

Weather Conditions and Grain Yield

Across our sites, climate conditions were relatively inconsistent across the growing season (April–October) during the years of study (Fig. 1). Compared with the 35-yr average, the end of season values for GDD and precipitation show roughly 47% of the site-years were warm, 42% cool, and 2% near mean values. The coolest site-year was at the Northeast site in 2014, and the warmest at the Southeast site in 2016. Regarding precipitation, 62% of the site-years were wet, 24% dry, and 14% near the mean yearly precipitation (data not shown). The wettest site-year was Southwest in 2014, and the driest was South Central in 2014. Overall, there was substantial weather variability across site-years. Accounting for PD within site-year the variability in growing season precipitation and GDD increased further (Fig. 1 and Supplemental Table 2). For instance, the 21 Apr. 2014

Table 3. Site means and standard deviation (SD) across planting date (PD) and relative maturity (RM) group. Including an analysis of variance for each treatment means effect on grain yield.

PD	RM	Northwest	North Central	Northeast	Central	Southwest	South Central	Southeast
		Mg ha^{-1}						
April	–	13.42	13.57	12.93	11.92	14.85	14.10	14.81
Early May	–	13.83	9.16	12.75	9.59	13.75	14.53	14.00
Mid-May	–	13.67	12.23	–	14.59	14.45	14.97	–
Early June	–	11.99	10.54	11.23	10.20	11.37	11.16	11.97
Late June	–	2.78	3.12	3.45	3.44	0.89	4.83	4.97
SD		2.74	1.89	1.86	2.41	1.72	2.48	2.31
	95	10.81	9.51	10.47	–	–	–	–
	104	10.02	9.08	9.70	8.96	–	–	–
	106	–	–	–	–	9.88	11.25	11.00
	109	11.27	9.91	10.10	9.59	–	–	–
	111	–	–	–	9.58	10.70	11.27	11.81
	113	–	–	–	8.46	10.40	11.16	11.51
	SD	5.25	4.32	4.31	4.58	5.88	4.66	4.51
ANOVA								
Planting date (PD)		***	***	***	***	***	***	***
Relative maturity (RM)		ns†	ns	ns	**	ns	ns	ns
PD × RM		ns	ns	ns	ns	ns	ns	ns

** $P < 0.01$.
*** $P < 0.0001$.
† ns, not significant.

(DOY 111) PD at Central received 150 mm more rain and 288 more GDD than the 3 June 2014 (DOY 154) PD.

A killing fall frost is a major yield-limiting factor for maize production in Iowa. Typically, a killing fall frost occurs in mid-October (Fig. 2). In 90% of the study site-years, the first fall frost occurred after the historical mean. This means that late plantings benefited from the extended growing season. The fall frost in Northeast in 2015 and South Central in 2016 were earlier than normal, but within the 25th percentile. About 71% of the site-years had a frost date later than the 75th percentile.

Despite the fact that only 1 to 2% of the site-years had precipitation and temperature near the historical mean, average grain yields across PD and RM were stable across the site-years. Grain yields were above, near, or below the county average 29, 38, and 33% of the cases, respectively (data not shown). Mean grain yields were higher in southern sites, followed by northern sites, with the lowest mean grain yields achieved in the central site.

Planting Date and Relative Maturity Effects on Grain Yield and Crop Phenology

Planting date had the strongest effect on grain yield. In all cases, April and early May PD had higher grain yields than the June PD. The full-season RM had significantly higher grain yields than the mid and short RM, with the exception of the Northeast site, this is due to the shortest RM reaching maturity before a killing frost on the last PD, whereas the other hybrid RM did not.

Analysis of variance for silking and maturity dates revealed significant interactions among study factors ($P < 0.0001$). Using the mean square error (MSE) derived from the ANOVA, percent variation to each factor was calculated using an individual factor's MSE divided by the sum MSE of all factors. This analysis attributed almost all of the observed variability (96% in silking date and 76% in maturity date) to PD whereas RM explained only 3 and 12% of the variability, respectively. Delays in PD caused statistically significant delays in silking date and maturity date and, therefore, shortened the vegetative and reproductive intervals. Between early (April) and late planting (June), the time from emergence to silking decreased from an average of 67 to 54 d. This decrease in days to silking was greater in the southern sites and smaller in the northern sites due to temperature gradients. The mid-April PD had a mean growing season length of 130 d. The growing season length decreased to 123, 120, 112, and 103 d for the early May, mid-May, early June, and late June planting, respectively (Supplemental Tables 1 and 2).

Optimum Planting Windows

The observed variability in grain yield response to PD across all the hybrid-specific models from each site-year ($n = 66$) is illustrated in Fig. 3 (model performance of the 66 individual regressions is included in Supplemental Table 3). The nonlinear model used to describe the observed grain yields performed well (average $R^2 = 0.91$) and allowed simulated data to be used to calculate the optimum PD for each site-year × RM combination. Optimum planting date for each site was realized on the DOY that had the highest grain yield for each year × RM interaction. Frequency analysis of the optimum PD revealed that the optimum planting window was narrower in northern sites and wider in southern sites, with the exception of the North Central site (Fig. 3). Interestingly, hybrid RM did not have a significant effect ($P = 0.3378$) on the optimum date and frequency distributions. Analysis of previous PD and RM research across the central Corn Belt found the optimum planting window to be 22 April (DOY 112) to 10 May (DOY 130) (Fig. 4). This corresponds with our optimum PD for the Central site.

To quantify the risk that is associated with using full-season hybrids under late planting conditions, we calculated the percent rate of yield loss from the maximum yield for every given RM × site interaction. Using predicted values derived from Eq. [2] curves were fit to represent yield losses from the observed data points (Fig. 5). Predicted values were also used

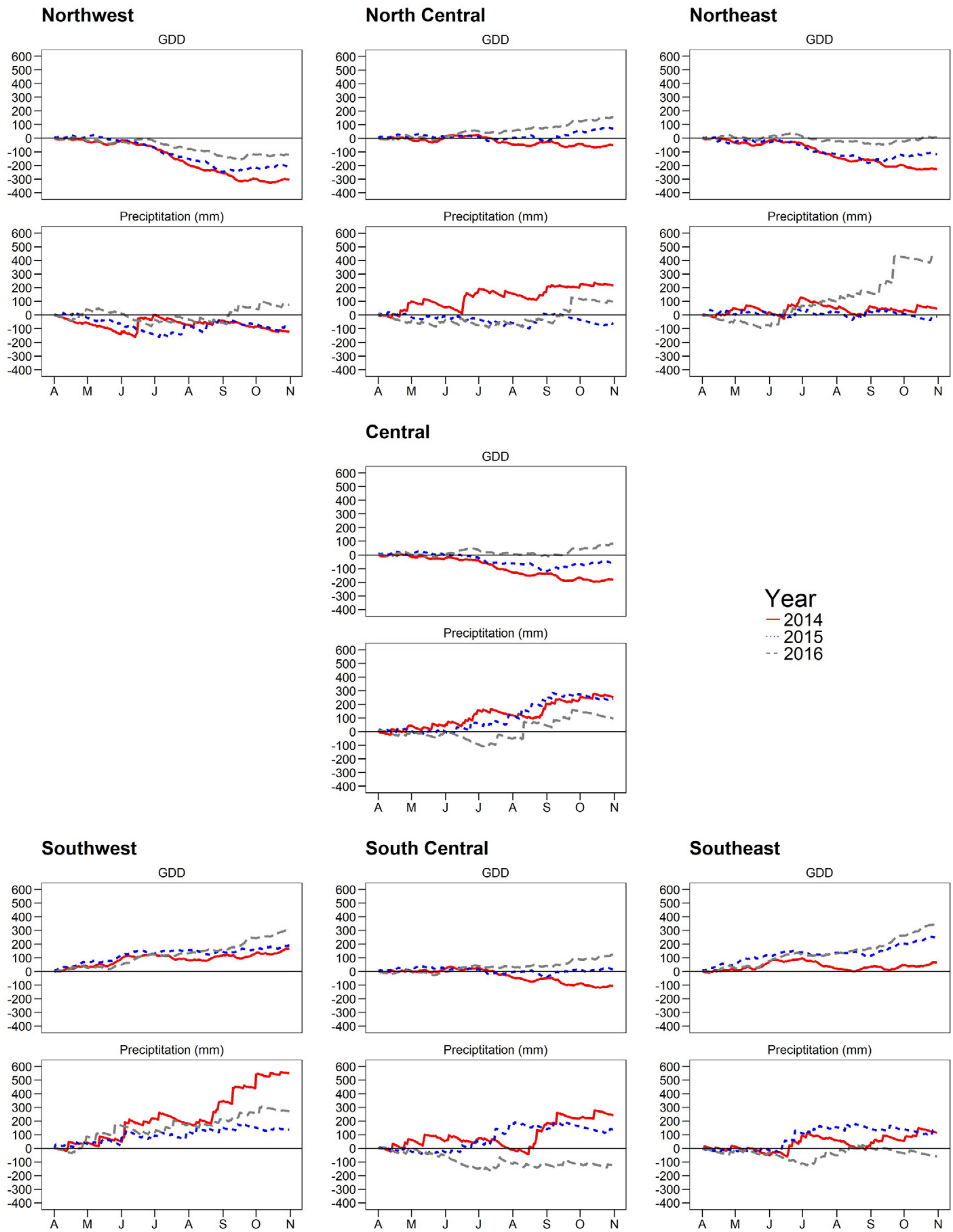

Fig. 1. The difference from climatological historical mean for precipitation (mm) and growing degree days (GDD) across the growing season (1 April–31October). The horizontal line at $y = 0$ represents the 35-yr mean for the site precipitation and GDD.

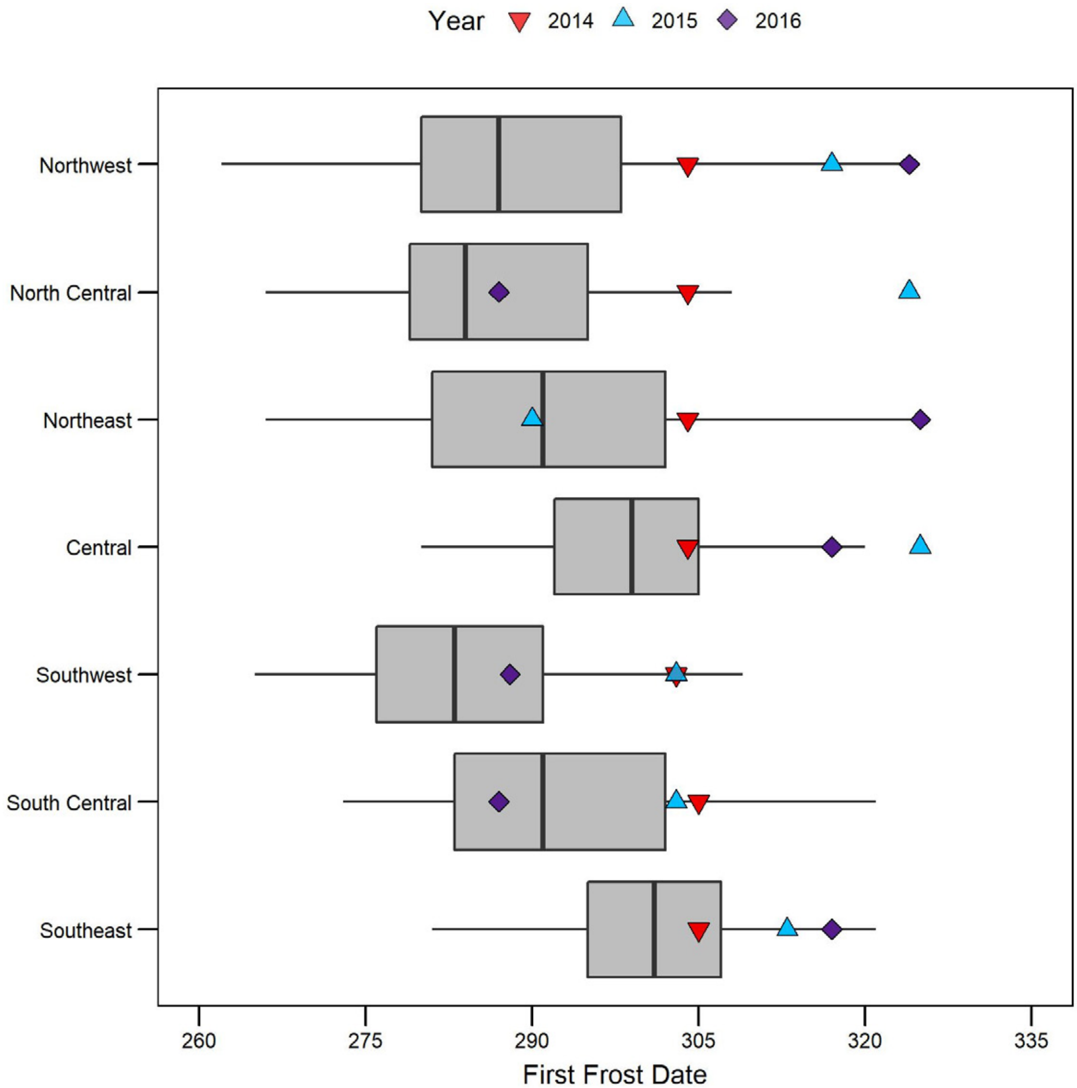

Fig. 2. Long-term fall frost data (boxplots; 1980–2016) and observed fall frost across study years (colored symbols) and locations. In the boxplot: middle line represents the mean frost date, the lower and upper hinges being the 25th and 75th percentiles, whiskers showing a 95% confidence interval around the mean. Ticks on the *x* axis represent day of year (DOY).

to determine the mean grain yield over 10-d planting intervals from late April through late June. These values ranged from 3 to 117 kg ha^{-1} d^{-1} in late April and 57 to −45 kg ha^{-1} d^{-1} in early May (Table 4) among each site-year × RM interaction for the respective PD interval. Relative maturity had a minor effect on the shape of yield response to PD, and thus mean values across RM were determined to assess the risk of yield loss. Sharp declines in grain yield change were realized beginning late May to early June, with maximum relative yield most frequently found in early May. Relative yield of >93% was achieved with planting in mid-May or earlier, whereas planting before early June resulted in >80% relative yield (Table 4).

Critical Silking Date and Grain-Filling Thresholds for Achieving Optimum Yields

Regression analysis among yield and key phenological events (Fig. 6) revealed important thresholds that can assist with yield predictions. The vegetative (emergence to silking) GDD threshold to achieve 100% relative yield was 702°C-day (Fig. 6c). Below that threshold relative yield was quite variable. In terms of a critical calendar date beyond which yield is reduced, we found this to be 23 July (DOY 204) across site-years (Fig. 6a). Silking beyond 23 July (DOY 204) was associated with a 0.75% yield loss for every day delay.

The relationship between yield and GDD during the grain-filling period was linear switching to a plateau at 648°C-day (Fig. 6d). This means that the minimum grain-filling requirement for maize to achieve maximum yield is 648°C-day. Below this threshold, grain yield sharply declined by a rate of 0.13% per GDD unit. In terms of calendar days, maize reaching maturity beyond 22 September (DOY 265) is associated with high risk of yield loss due to decreased daily radiation amounts, low temperatures, and frost risk.

DISCUSSION

We analyzed a wide range of PD and RM combinations across different geographies and weather conditions in Iowa. Such a comprehensive analysis was missing for the top maize-producing state in the United States. These results are expected to assist farmer's decision-making as well as researchers involved in yield predictions.

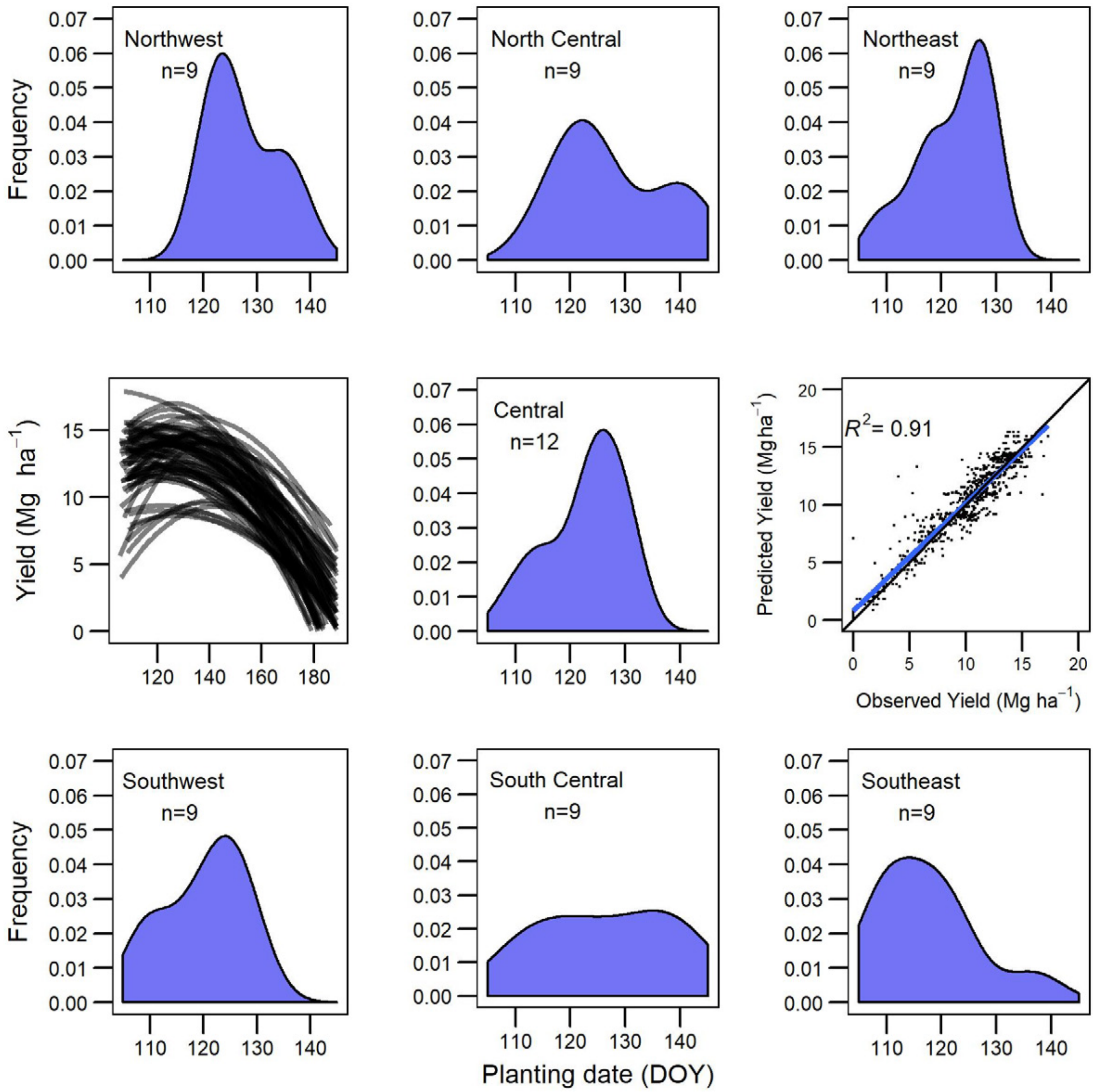

Fig. 3. Distribution of the optimum planting dates (PD) across locations. Left center is an illustration of quadratic response curve variability for each individual hybrid maturity site-year (*n* = 66). Right center is an illustration of the measured vs. predicted grain yield for each PD, relative maturity (RM), and site-year.

Assuming that most of the maize hybrids grown in Iowa have around 18 leaves, meaning the vegetative phase requires a thermal time requirement of approximately 720°C-day, given that the leaf appearance rate is about 40°C-day per leaf (Bonelli et al., 2016). Extending the vegetative phase up to 23 July (DOY 204) often results in higher grain yields in the absence of other yield-reducing factors such as nutrients, water, and killing frost. However, the duration of grain-filling phase is also important. Silking after 23 July (DOY 204) led to a less favorable grain-filling environment, both lower quality and quantity of solar radiation and cooler temperatures at the end of the grain-filling phase (Cirilo and Andrade, 1994). This, coupled with increased leaf senescence after silking and slower GDD accumulation (Tsimba et al., 2013a), limits assimilate supply during grain filling and negatively impacts yield. These factors increase the risk of the crop not maturating before an early fall frost.

The fact that our study was conducted over a 3-yr period where fall frost occurred later than the historical mean is one reason why we did not find hybrid RM to be an effective management consideration in response to late planting. Relative

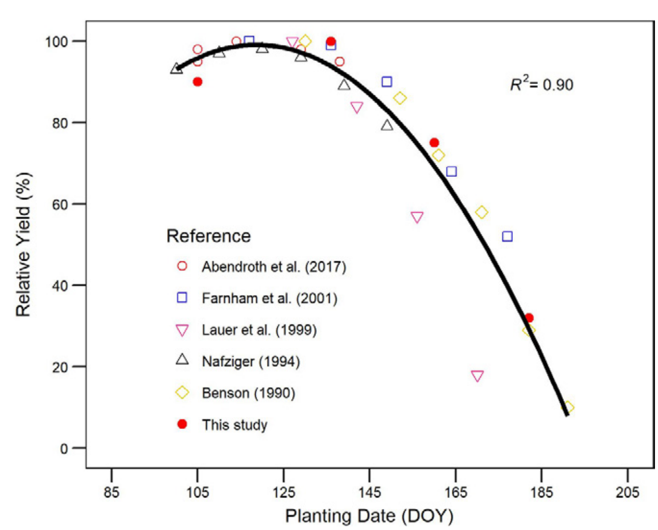

Fig. 4. Summary of five experiments conducted in the central Corn Belt, USA, from 1994 to 2016 with the 2016 Central site-year for comparison purposes.

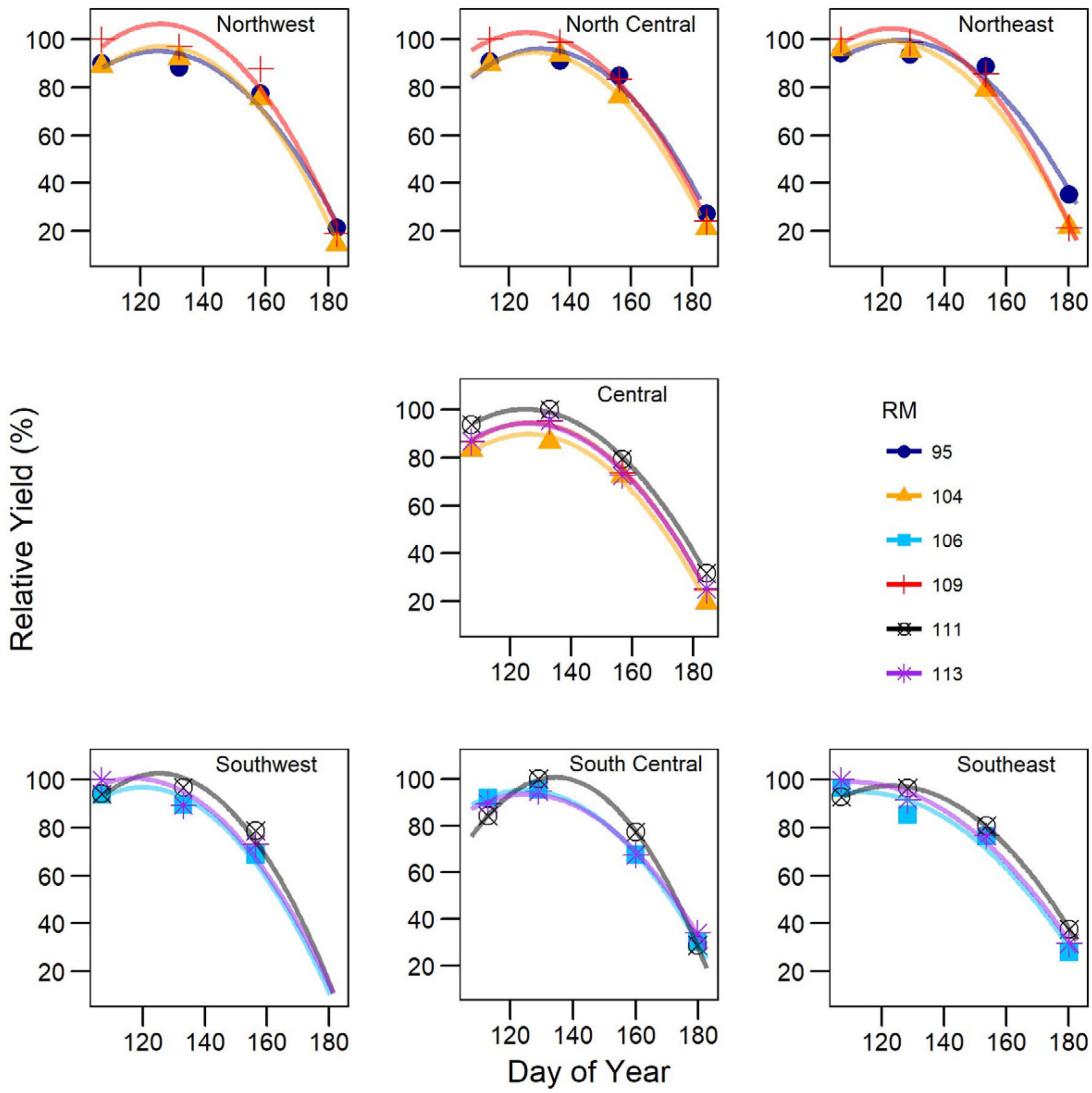

Fig. 5. Relative maize yield response to planting date (PD). Shape and color denote the individual hybrid relative maturities. Lines are predicted values of the site-year by hybrid combination and the points represent actual data.

maturity has been used in the past to minimize yield penalties associated with late planting with the explicit goal of reaching physiological maturity before a killing fall frost, as well as having suitable conditions for adequate grain moisture dry down in the field. Farmers must also consider the time for grain to dry down when physiological maturity is delayed. Grain moisture dry down following physiological maturity is driven by the vapor pressure deficit of the grain and atmosphere (Maiorano et al., 2014). Because later PD results in the crop reaching physiological maturity later in the growing season, there is less potential for grain moisture dry down in the field following physiological maturity due to the temperature being cooler, causing less of a vapor pressure deficit (Nielsen, 2013). The combination of low yield and high grain moisture has the potential to dramatically reduce profits due to increased drying cost and lower receipts from grain yield.

Despite climate patterns, yield response to PD have not changed for central Iowa according to literature findings (Alessi and Power, 1975; Cirilo and Andrade, 1994; Lauer et al., 1999; Farnham et al., 2001; Sindelar et al., 2010; Parker et al., 2016; Abendroth et al., 2017). This is largely the result of more stable hybrids that tolerate weather variability. Our observed grain yield variability (CV = 31.29%) among site-years is consistent with observed yields for another study planted at the same sites (Al-Kaisi et al., 2015).

In cropping areas, such as the US Corn Belt, very early PD are expected to have a yield penalty as a result of cool, wet soil conditions (Kucharik, 2008). However, our study was mainly focused on late planting situations, due to the fact that our earliest PDs were not early enough to detect such a yield penalty. We found that typically, the optimal PD was around 5 May (DOY 125). Our study indicates a disproportionate amount of time a farmer has to plant in the optimum window. It was found that our sites in northern Iowa has a smaller optimal planting window than the central and southern Iowa sites due to a delay in the time ideal planting soil temperature and moisture are achieved. This indicates a greater importance for farmers in northern Iowa to plant timely to attain maximum grain yield. We believe the cause of this is due to the warmer growing environment during grainfill in southern Iowa, allowing later planted maize to accumulate adequate GDD units to fully progress through reproductive stages. Likewise, the highest frequency of optimum PD was

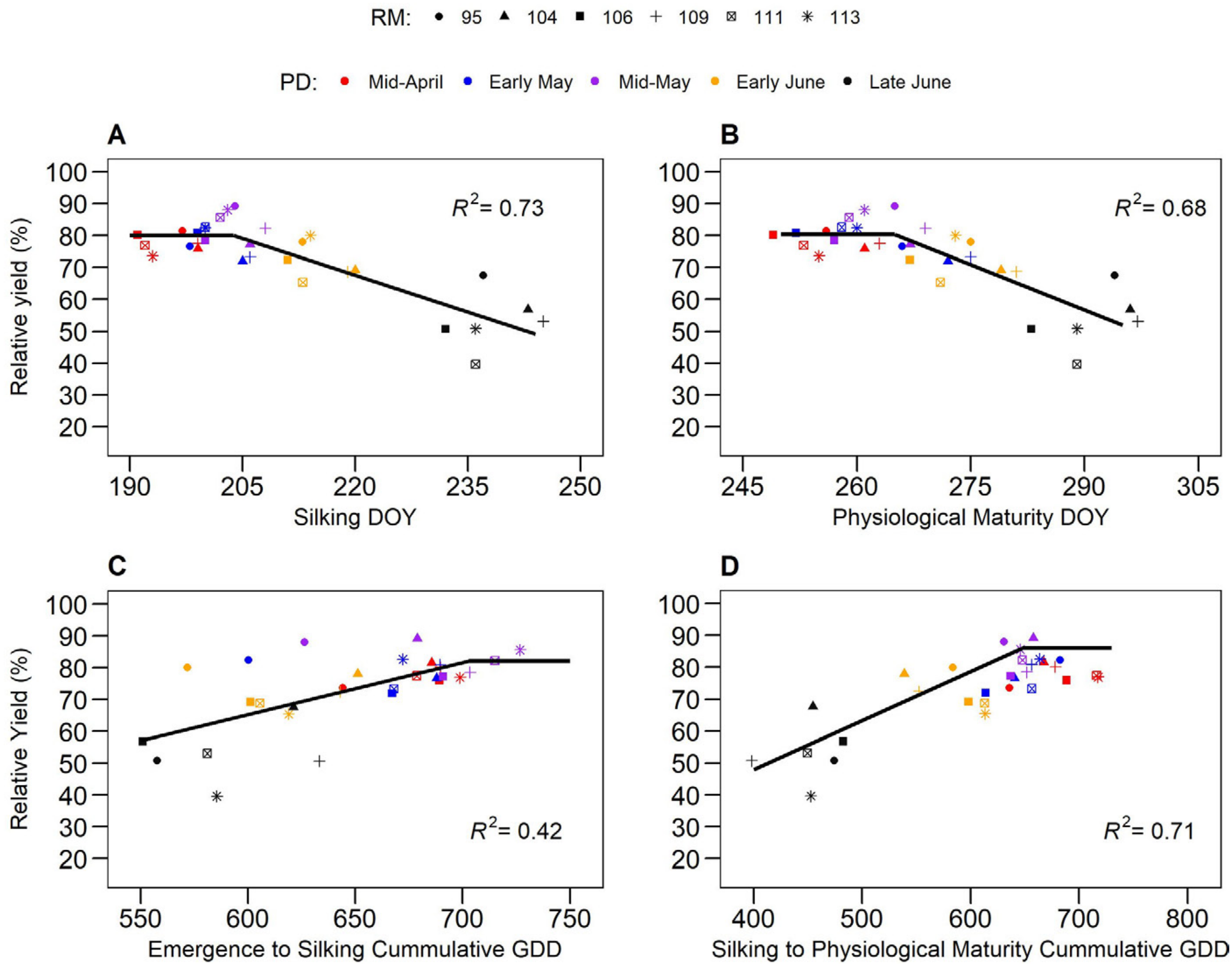

Fig. 6. Relationships among relative grain yield and calendar days, and thermal time for key phenological events. Each symbol represents a site-year × hybrid combination. (A) Relative maize yield vs. silking DOY. (B) Relative maize yield vs. physiological maturity DOY. (C) Relative maize yield vs. silking time expressed as growing degree days (GDD) from emergence. (D) Relative maize yield vs. maturity time expressed as GDD from silking.

Table 4. Means of grain yield changes and relative yield per 10-d planting interval in response to planting delays across hybrid relative maturity and year for each site.†

	Northwest	North Central	Northeast	Central	Southwest	South Central	Southeast
				Change in mean grain yield, kg ha^{-1} d^{-1}			
Late April	76	103	37	39	34	117	3
Early May	–2	57	–24	–14	–45	32	–43
Mid-May	–67	6	–78	–58	–107	–42	–86
Late May	–141	–40	–134	–110	–183	–120	–131
Early June	–204	–87	–183	–151	–244	–192	–168
Mid-June	–272	–133	–237	–196	–313	–266	–211
Late June	–391	–173	–329	–258	–439	–383	–285
				Relative yield, %			
Late April	96.8	96.8	99.3	98.4	100.0	93.9	100.0
Early May	100.0	100.0	100.0	100.0	99.5	100.0	98.3
Mid-May	97.2	98.3	95.4	96.8	93.6	99.6	93.2
Late May	88.4	91.7	85.6	88.9	81.9	92.7	84.1
Early June	73.9	80.5	70.9	76.6	64.7	79.4	71.6
Mid-June	55.0	65.4	52.3	61.2	43.1	60.8	56.4
Late June	31.4	46.3	29.6	42.4	17.4	37.2	38.5

† The bottom section contains relative yield in which the mean grain yield during the 10-d interval is divided by the highest mean grain yield per interval for each individual site.

earlier in the growing season and was delayed at higher latitudes, which matches the results of (Long et al., 2017).

Late planting of maize has a tremendous impact on both the vegetative growth and grain-filling phase. Tsimba et al. (2013b) found decreased harvest index associated with a late PD because late planting reduced grain filling whereas vegetative biomass was not affected. Not only does limiting grain filling result in smaller ears and reduced kernel weight, but full-season hybrids were either not matured fully or had a higher grain moisture content than earlier planting dates. It is recommended to have 15% maize grain moisture at the time of sale and 14% grain moisture for proper storage. Harvesting maize at substantially higher grain moisture greatly increases expenses associated with transporting and drying, thereby lowering farmer profits. Therefore, this must be a consideration for late planted maize (Benson, 1990).

Previous research has found grain yield of full-season hybrids to be greater than short-season hybrids when planted earlier in the growing season, whereas short-season hybrids have a grain yield advantage when planted later (Staggenborg et al., 1999). Our study confirmed that full-season hybrids have a slightly higher relative yield compared with short-season hybrids at April to early May PD. However, we found that RM was not an important yield consideration with late May to late June PD. This contradicts Farnham et al. (2001), who found small yield benefits from 5 RM shorter hybrid for every 7- to 10-d delay in planting past the optimal planting window. One of the risks of planting full-season hybrids later in the growing season is the increased risk of a killing fall frost before the crop matures (Tsimba et al., 2013b).

CONCLUSION

Planting date greatly affects maize grain yields, time to silking, and grain-filling duration. The effect from PD was larger than RM on grain yield and phenology. Farmers in Iowa will benefit more from planting full-season hybrids throughout the growing season; however, the effect of RM dissipates with movement to warmer southern climates, as southern climates have a longer growing season. The yield penalty associated with delayed planting was attributed to a shortened growing season. Farmers have typically chosen a hybrid relative maturity well before planting, our research suggest that hybrid RM has a very small effect on grain yield for any given PD when the crop reaches maturity before a killing frost. In areas that are prone to an earlier frost such as in northern Iowa, farmers may benefit from switching to a shorter season RM on later PD to increase the chance of the crop maturing before a killing fall frost. With new hybrids entering the market each year, it is important to maintain an understanding of how these hybrids interact with PD so farmers have the best recommendations possible.

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SUPPLEMENTAL MATERIAL

Supplemental Table 1. Statistical analysis of the date of the crop phenological stage.

Supplemental Table 2. Statistical analysis of the growing degree days per interval of crop phenological stage.

Supplemental Table 3. Model parameters and goodness of fit of the quadratic model used to create the 66 lines in Fig. 3.

REFERENCES

Abendroth, L.J., K.P. Woli, A.J.W. Myers, and R.W. Elmore. 2017. Yield-based corn planting date recommendation windows for Iowa. Crop Forage Turfgrass Manage. 3. doi:10.2134/cftm2017.02.0015

Al-Kaisi, M.M., S.V. Archontoulis, D. Kwaw-Mensah, and F. Miguez. 2015. Tillage and crop rotation effects on corn agronomic response and economic return at seven Iowa locations. Agron. J. 107:1411–1424. doi:10.2134/agronj14.0470

Alessi, J., and J.F. Power. 1975. Response of an early-maturing corn hybrid to planting date and population in the northern plains. Agron. J. 67:762–765. doi:10.2134/agronj1975.00021962006700060009x

Alter, R.E., H.C. Douglas, J.M. Winter, and E.A.B. Eltahir. 2017. Twentieth century regional climate change during the summer in the central United States attributed to agricultural intensification. Geophys. Res. Lett. 45:1586–1594. doi:10.1002/2017GL075604

Andrade, F.H., M.E. Otegui, and C. Vega. 2000. Intercepted radiation at flowering and kernel number of maize. Agron. J. 92:92–97. doi:10.2134/agronj2000.92192x

Benson, G.O. 1990. Corn replant decisions: A review. J. Prod. Agric. 3:180–184. doi:10.2134/jpa1990.0180

Bonelli, L.E., J.P. Monzon, A. Cerrudo, R.H. Rizzalli, and F.H. Andrade. 2016. Maize grain yield components and source-sink relationship as affected by the delay in sowing date. Field Crops Res. 198:215–225. doi:10.1016/j.fcr.2016.09.003

Cirilo, A.G., and F.H. Andrade. 1994. Sowing date and maize productivity: I. Crop growth and dry matter partitioning. Crop Sci. 34:1039–1043. doi:10.2135/cropsci1994.0011183X003400040037x

Dai, S., M.D. Shulski, K.G. Hubbard, and E.S. Takle. 2015. A spatiotemporal analysis of Midwest US temperature and precipitation trends during the growing season from 1980–2013. Int. J. Climatol. 36:517–525. doi:10.1002/joc.4354

Edmeades, G.O., J. Bolaños, A. Elings, J.-M. Ribaut, M. Bänziger, and M.E. Westgate. 2000. The role and regulation of the anthesis-silking interval in maize. In: M. Westgate and K. Boote, editors, Physiology and modeling kernel set in maize. CSSA Spec. Publ. 29. CSSA and ASA, Madison, WI. p. 43–73. doi:10.2135/cssaspecpub29.c4

Farnham, D.E., J. Myli, and K.T. Pecinovsky. 2001. Planting date and hybrid maturity effects on corn yield in Iowa. Farm Progress Reports 1714. Iowa State Univ., Ames, IA. https://lib.dr.iastate.edu/farms_reports/1714 (accessed 25 Apr. 2018).

Iowa Environmental Mesonet. 2016. Daily summary data. Iowa State Univ., Ames, IA. http://mesonet.agron.iastate.edu/agclimate/hist/dailyindex.php (accessed 12 Feb. 2017).

Kucharik, C.J. 2008. Contribution of planting date trends to increased maize yields in the central United States. Agron. J. 100:328–336. doi:10.2134/agronj2007.0145

Kumudini, S., F.H. Andrade, K.J. Boote, G.A. Brown, K.A. Dzotsi, G.O. Edmeades, T. Gocken, M. Goodwin, A.L. Halter, G.L. Hammer, J.L. Hatfield, J.W. Jones, A.R. Kemanian, S.H. Kim, J. Kiniry, J.I. Lizaso, C. Nendel, R.L. Nielsen, B. Parent, C.O. Stöckle, F. Tardieu, P.R. Thomison, D.J. Timlin, T.J. Vyn, D. Wallach, H.S. Yang, and M. Tollenaar. 2014. Predicting maize phenology: Intercomparison of functions for developmental response to temperature. Agron. J. 106:2087–2097. doi:10.2134/agronj14.0200

Lauer, J.G., P.R. Carter, T.M. Wood, G. Diezel, D.W. Wiersma, R.E. Rand, and M.J. Mlynarek. 1999. Corn hybrid response to planting date in the northern Corn Belt. Agron. J. 91:834–839. doi:10.2134/agronj1999.915834x

Lindquist, J.L., T.J. Arkebauer, D.T. Walters, K.G. Cassman, and A. Dobermann. 2005. Maize radiation use efficiency under optimal growth conditions. Agron. J. 97:72–78. doi:10.2134/agronj2005.0072

Long, N.V., Y. Assefa, R. Schwalbert, and I.A. Ciampitti. 2017. Maize yield and planting date relationship: A synthesis-analysis for US high-yielding contest winner and field research data. Front. Plant Sci. doi:10.3389/fpls.2017.02106

Maiorano, A., D. Fanchini, and M. Donatelli. 2014. MIMYCS.Moisture, a process-based model of moisture content in developing maize kernels. Eur. J. Agron. doi:10.1016/j.eja.2014.05.011

Mallarino, A.P., J.E. Sawyer, and S.K. Barnhart. 2013. A general guide for crop nutrient and limestone recommendations in Iowa. PM 1688. Iowa State Univ. Extension and Outreach, Ames, IA.

Nafziger, E.D. 1994. Corn planting date and plant population. J. Prod. Agric. 7:59–62. doi:10.2134/jpa1994.0059

Nielsen, R.L. 2013. Field dry down of mature corn grain. https://www.agry.purdue.edu/ext/corn/news/timeless/graindrying.html (accessed 1 July 2018).

Nielsen, R.L., P.R. Thomison, G.A. Brown, A.L. Halter, J. Wells, and K.L. Wuethrich. 2002. Delayed planting effects on flowering and grain maturation of dent corn. Agron. J. 94:549–558. doi:10.2134/agronj2002.5490

Parker, P.S., J.S. Shonkwiler, and J. Aurbacher. 2016. Cause and consequence in maize planting dates in Germany. J. Agron. Crop Sci. 203:1–14. doi:10.1111/jac.12182

Richards, R.A. 1996. Increasing yield potential in wheat: Manipulating sources and sinks. In: M.P. Reynolds, R. Rajaram, and A. McNab, editors, Increasing yield potential in wheat: Braking the barriers. CIMMYT, Mexico City, Mexico. p. 134–149.

Sacks, W.J., and C. J. Kucharik. 2011. Crop management and phenology trends in the U.S. Corn Belt: Impacts on yields, evapotranspiration and energy balance. Agric. For. Meteorol. 151:882–894. doi:10.1016/j.agrformet.2011.02.010

Sindelar, A.J., K.L. Roozeboom, W.B. Gordon, and W.F. Heer. 2010. Corn response to delayed planting in the central great plains. Agron. J. 102:530–536. doi:10.2134/agronj2009.0311

Staggenborg, S., D. Fjell, D. Devlin, W. Gordon, L. Maddux, and B. Marsh. 1999. Selecting optimum planting dates and plant populations for dryland corn in Kansas. J. Prod. Agric. 12:85–90. doi:10.2134/jpa1999.0085

R Core Team. 2017. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.r-project.org/ (accessed 30 Nov. 2017).

Tsimba, R., G.O. Edmeades, J.P. Millner, and P.D. Kemp. 2013a. The effect of planting date on maize: Phenology, thermal time durations and growth rates in a cool temperate climate. Field Crops Res. 150:145–155. doi:10.1016/j.fcr.2013.05.021

Tsimba, R., G.O. Edmeades, J.P. Millner, and P.D. Kemp. 2013b. The effect of planting date on maize grain yields and yield components. Field Crops Res. 150:135–144. doi:10.1016/j.fcr.2013.05.028

USDA-NASS. 2017. Crop production 2016 summary. USDA-NASS, Washington, DC. http://usda.mannlib.cornell.edu/usda/nass/CropProdSu//2010s/2017/CropProdSu-01-12-2017.pdf (accessed 25 Apr. 2018).

Vega, C.R.C., F.H. Andrade, V.O. Sadras, S.A. Uhart, and O.R. Valentinuz. 2001. Seed number as a function of growth. A comparative study in soybean, sunflower, and maize. Crop Sci. 41:748–754. doi:10.2135/cropsci2001.413748x

Zhou, B., Y. Yue, X. Sun, X. Wang, Z. Wang, W. Ma, and M. Zhao. 2016. Maize grain yield and dry matter production responses to variations in weather conditions. Agron. J. 108:196–204. doi:10.2134/agronj2015.0196

Supplemental material

Supplemental Table 1. Statistical analysis of the date of the crop phenological stage. Dash mark represent no data since hybrid relative maturity was nested within site and not all sites had all hybrid relative maturities.

		Emergence DOY							Silking DOY							Physiological Maturity DOY						
PD	RM	Northwest	North Central	Northeast	Central	Southwest	South Central	Southeast	Northwest	North Central	Northeast	Central	Southwest	South Central	Southeast	Northwest	North Central	Northeast	Central	Southwest	South Central	Southeast
		DOY	DOY	DOY	DOY	DOY	DOY	DOY	DOY	DOY	DOY	DOY	DOY	DOY	DOY	DOY	DOY	DOY	DOY	DOY	DOY	DOY
April		131	127	129	128	124	126	125	200	201	200	193	193	195	189	261	261	264	256	262	240	249
Early May		142	139	143	139	141	139	140	201	203	203	209	199	201	197	269	278	268	281	271	250	254
Mid-May		148	146	-	143	144	144	-	209	206	-	205	203	198	-	264	272	-	262	272	230	-
Early June		165	162	160	165	161	167	160	220	218	215	217	211	214	211	277	281	282	273	284	260	268
Late June		189	189	186	190	188	187	186	238	248	239	244	238	227	233	297	298	293	295	294	270	293
sd		3.85	2.51	1.93	3.34	1.59	2.53	2.87	5.65	7.67	4.07	7.21	2.29	6.19	2.60	10.73	6.17	7.50	10.16	5.58	11.11	7.23
	95	157	157	154	-	-	-	-	212	214	210	-	-	-	-	267	273	271	-	-	-	-
	104	157	157	154	153	-	-	-	216	220	216	213	-	-	-	270	279	272	271	-	-	-
	106	-	-	-	-	154	156	152	-	-	-	-	210	209	207	-	-	-	-	269	253	163
	109	157	157	155	155	-	-	-	217	221	217	214	-	-	-	274	281	279	271	-	-	-
	111	-	-	-	159	154	156	152	-	-	-	217	210	209	207	-	-	-	276	275	253	265
	113	-	-	-	156	154	156	152	-	-	-	214	212	209	208	-	-	-	270	281	253	269
	sd	22.50	22.05	21.20	23.50	23.75	22.61	23.25	16.19	19.73	15.52	19.86	16.92	13.45	16.84	14.16	12.77	11.55	17.37	11.10	16.37	18.31
ANOVA																						
Planting date (PD)		***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Relative Maturity (RM)		ns	ns	ns	ns	ns	ns	ns	***	***	***	ns	***	ns	ns	**	***	***	ns	***	ns	***
PD x RM		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	**	ns	ns	***	ns	ns

* < 0.05
** < 0.01
*** < 0.0001
ns = not significant

Supplemental Table 2. Statistical analysis of the growing degree days per interval of crop phenological stage. Dash mark represent no data since hybrid relative maturity was nested within site and not all sites had all hybrid relative maturities.

		GGD Emergence to Silking							GDD SIlking to Physiological Maturity							GDD Emergence to Physiological Maturity						
PD	RM	Northwest	North Central	Northeast	Central	Southwest	South Central	Southeast	Northwest	North Central	Northeast	Central	Southwest	South Central	Southeast	Northwest	North Central	Northeast	Central	Southwest	South Central	Southeast
		GDD	GDD	GDD	GDD	GDD	GDD	GDD	GDD	GDD	GDD	GDD	GDD	GDD	GDD	GDD	GDD	GDD	GDD	GDD	GDD	GDD
April	-	660	709	677	651	727	670	685	616	682	677	712	777	537	742	1276	1392	1345	1363	1504	1207	1427
Early May	-	639	675	643	762	673	637	673	657	689	657	672	749	544	713	1296	1365	1300	1435	1423	1181	1386
Mid-May	-	639	660	-	736	738	637	-	558	670	-	668	745	412	-	1197	1331	-	1403	1484	1048	-
Early June	-	600	649	611	633	625	567	645	509	578	595	568	697	490	654	1110	1218	1207	1201	1322	1056	1300
Late June	-	550	640	567	640	610	481	594	463	446	465	410	412	473	540	1018	1082	1020	1054	970	913	1151
sd		40.30	45.91	43.30	62.63	37.91	76.73	31.30	47.59	55.60	45.64	98.06	58.27	98.60	55.07	49.78	48.34	46.43	73.17	69.10	121.05	66.62
	95	581	620	584	-	-	-	-	571	621	629	-	-	-	-	1163	1240	1213	-	-	-	-
	104	633	674	658	684	-	-	-	586	608	622	597	-	-	-	1231	1281	1291	1281	-	-	-
	106	-	-	-	-	659	592	637	-	-	-	-	686	502	663	-	-	-	-	1352	1095	1306
	109	637	694	663	669	-	-	-	568	607	640	590	-	-	-	1216	1299	1314	1259	-	-	-
	111	-	-	-	661	666	585	651	-	-	-	593	720	507	669	-	-	-	1254	1392	1093	1326
	113	-	-	-	660	693	593	664	-	-	-	601	734	503	686	-	-	-	1265	1433	1097	1357
	sd	50.64	41.36	38.17	76.98	64.46	103.05	45.14	79.66	102.40	73.10	149.02	109.70	106.77	89.82	100.81	114.59	92.04	156.43	159.30	159.35	116.66
ANOVA																						
Planting date (PD)		***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Relative Maturity (RM)		***	***	***	***	***	ns	***	ns	*	***	*	***	ns	***	***	***	***	*	***	ns	***
PD x RM		***	***	***	***	*	ns	ns	***	***	ns	***	***	ns	***	***	***	*	***	***	ns	***

* < 0.05
** < 0.01
*** < 0.0001
ns = not significant

Supplemental Table 3. Model parameters and goodness of fit of the quadratic model used to create the 66 lines in figure 3.

			Coefficients			
Site	Year	Maturity Group	a	b	c	R^2
Northwest	2014	95	0.8607381	-0.0034253	-42.289469	0.99
Northwest	2014	104	0.6681621	-0.0027756	-28.973128	0.99
Northwest	2014	109	0.7949487	-0.0032431	-36.442611	0.99
Northwest	2015	95	1.0225374	-0.0041067	-49.79278	0.93
Northwest	2015	104	1.0054525	-0.0041276	-46.121101	0.94
Northwest	2015	109	1.3622765	-0.0053916	-69.057515	0.91
Northwest	2016	95	0.587969	-0.0022071	-24.984335	0.78
Northwest	2016	104	1.1124901	-0.0040156	-62.201061	0.87
Northwest	2016	109	0.8968915	-0.0033301	-44.391458	0.84
North Central	2014	95	1.0883219	-0.0038886	-66.423729	0.90
North Central	2014	104	1.1621673	-0.0040888	-73.276801	0.86
North Central	2014	109	0.935469	-0.0034125	-54.562939	0.93
North Central	2015	95	0.5787858	-0.0023147	-24.092601	0.91
North Central	2015	104	0.528397	-0.0022399	-19.624964	0.96
North Central	2015	109	0.4891796	-0.0020999	-15.362713	0.97
North Central	2016	95	0.5673342	-0.0022713	-22.2807621	0.94
North Central	2016	104	0.5936081	-0.0024159	-22.5695897	0.96
North Central	2016	109	0.7181702	-0.0029127	-29.3226185	0.98
Northeast	2014	95	1.1400359	-0.0044255	-61.863733	0.92
Northeast	2014	104	1.1180255	-0.004393	-59.105424	0.97
Northeast	2014	109	0.8878266	-0.0036706	-41.200167	0.97
Northeast	2015	95	0.467527	-0.0019767	-13.626308	0.93
Northeast	2015	104	0.3042418	-0.0015487	-1.1078395	0.96
Northeast	2015	109	0.6124875	-0.0025967	-21.867065	0.93
Northeast	2016	95	0.3957023	-0.001575	-13.024024	0.86
Northeast	2016	104	0.6439938	-0.0025366	-28.667363	0.97
Northeast	2016	109	0.7235755	-0.0028362	-33.644163	0.93
Central	2014	104	0.7016983	-0.0026696	-37.181349	0.86
Central	2014	109	0.4261955	-0.0017619	-16.787506	0.70
Central	2014	111	0.4634294	-0.0019007	-18.882087	0.91
Central	2014	113	0.5078182	-0.0019877	-23.822298	0.86
Central	2015	104	0.4253044	-0.0018512	-12.848967	0.88
Central	2015	109	0.8207761	-0.0031719	-40.475976	0.87
Central	2015	111	0.4656602	-0.0020647	-11.359392	0.91
Central	2015	113	0.761402	-0.0030496	-33.629685	0.86
Central	2016	104	0.950802	-0.0036686	-47.0556319	0.94
Central	2016	109	0.825137	-0.0032836	-36.6437671	0.83
Central	2016	111	0.339483	-0.0017040	-1.0705001	0.98
Central	2016	113	0.749779	-0.0029957	-32.8411857	0.96
Southwest	2014	106	0.131213	-0.0009958	11.105976	0.95
Southwest	2014	111	0.5564149	-0.0024147	-17.425226	0.96
Southwest	2014	113	0.3494551	-0.0017492	-2.236959	0.97
Southwest	2015	106	1.0135816	-0.0040485	-49.92995	0.92
Southwest	2015	111	1.3455577	-0.0051897	-72.639552	0.87
Southwest	2015	113	0.8627434	-0.0035784	-38.035887	0.92
Southwest	2016	106	0.2553689	-0.0011434	-3.9272047	0.93
Southwest	2016	111	0.671299	-0.0026611	-31.959481	0.89
Southwest	2016	113	0.3917737	-0.0016212	-14.003833	0.93
South Central	2014	106	1.8791842	-0.006784	-115.03711	0.90
South Central	2014	111	1.2661186	-0.0046103	-72.910876	0.50
South Central	2014	113	1.8747221	-0.0066024	-118.71634	0.52
South Central	2015	106	0.6125823	-0.0026148	-23.716485	0.96
South Central	2015	111	1.4521385	-0.005466	-81.84601	0.84
South Central	2015	113	0.4455971	-0.0020573	-10.691017	0.94
South Central	2016	106	0.3786250	-0.0017085	-5.4238438	0.92
South Central	2016	111	1.0580559	-0.0041483	-52.0649483	0.89
South Central	2016	113	0.5869418	-0.0024286	-20.9766111	0.93
Southeast	2014	106	0.469937	-0.0020885	-13.865006	0.93
Southeast	2014	111	0.9405627	-0.0038478	-43.433936	0.98
Southeast	2014	113	0.7756758	-0.0032823	-32.268794	0.94
Southeast	2015	106	0.370016	-0.001824	-4.524876	0.91
Southeast	2015	111	0.1835254	-0.0010774	8.2268264	0.86
Southeast	2015	113	0.080796	-0.000691	14.751701	0.84
Southeast	2016	106	0.542468	-0.0022241	-18.505928	0.86
Southeast	2016	111	0.8337362	-0.0030385	-43.12571	0.31
Southeast	2016	113	0.5307509	-0.0022262	-17.502858	0.97